PHYTOREMEDIATION OF THE ENVIRONMENT POLLUTED BY HEAVY METALS: HOW METAL-ACCUMULATING PLANTS CAN HELP US?

Lj. Jovanović, M. Marković, S.Cupać, V. Janjić, Lj. Šantrić,*
*M. Šarić**, Dj. Čokeša***, V. Andrić****
ARI SERBIA, Pesticides and Environmental Research Center;
Belgrade, Yugoslavia, Email: jovainko@EUnet.yu
**Faculty of Agriculture; Belgrade, Yugoslavia*
***Serbian Academy of Sciences and Arts; Belgrade, Yugoslavia*
****The Vinča Institute of Nuclear Sciences, Belgrade, Yugoslavia*

ABSTRACT

The paper discusses a new method of cleaning up soils polluted by heavy metals and radio nuclides and other wastes using plants. The method, known as phytoremediation, has proved to be effective in many aspects in cleaning up heavy metals from soil. Besides, it is cost-effective and environmentally-friendly. Most wild plants that can be used for phytoremediation due to their high ability to absorb different pollutants have low total biomass calculated per hectare and year. However, crop plants, even those with lower ability to absorb pollutants, have high biomass per hectare and year and are therefore very promising candidates for future use as phytoremediators. To prove that, we present here the results of investigation of crops and wild plants done in Serbia's former uranium mine Kalna. In laboratory conditions, experiments on sunflower roots and whole plants showed a high potential of uranium absorption.

Key words: polluted soil, heavy metals, radionuclides, phytoremediation

INTRODUCTION

Owing to technological development, human life has improved in many ways. However, industry in general produces some by-products (pollutants) which could be harmful to the environment (Meagher, 2000). Most such industrial pollutants are metals or some other anthropogenic waste. Those metals, even at low concentrations, can be absorbed by plants or reach underground water. Plants growing in such area could also be toxic to livestock. There are over 1.400.000 sites in Europe contaminated with heavy metals and other toxic materials, including radio nuclides. Conventional technologies for cleaning up pollutants usually include the removing, treating and replacing of contaminated soil. Besides the fact that those techniques are very expensive, they also change soil properties (leave it biologically inactive) and affect the environment. As for radio nuclides (uranium, etc.), up to 1 m layer of soil has to be removed and transferred to a safer place. Also, some chemicals can be added to soil (citrate) to improve uranium solubility and leaching in deeper soil layers, which may pollute underground water. In case of toxic metals, the usual method is to add EDTA, EGTA (Sun *et al.,* 2001) to soil to improve metal bioavailability to plants or leaching into deeper layers.

Phytoremediation is a completely different and promising method for cleaning up polluted soils (Chaney, 1983; Chaney *et al.,* 1997; Raskin *et al.*, 1997, 1994; McGrath, 1998). It is defined as the use of green plants to remove pollutants from the environment. Plants having the ability to accumulate hundreds or thousands of times more metals than ordinary plants are known as hyper-accumulators (Baker and Brooks, 1989; Lovley and Coates, 1997). During the growing period plants uptake and accumulate metal(s) in root and above-ground parts using different uptake mechanisms (Williams *et al.,* 2000). Fully developed plants are harvested, dried and then burned in heating systems. Metals from their ashes are extracted and, if expensive (Brooks et al., 1998), could be purified and sold. Otherwise, such metals need to be stored at a safe place. Natural hyper-accumulator plants can also be used as a crop over the low-grade ore body or mineralized soils. For example, the wild plant *Streptanthus polygaloides* growing near an exhaused Ni mine with ore concentration below commercial use (0.1% Ni in soil) has made a net return of about 500$ per ha (Brooks et al., 1998). Over 400 hyper accumulators, mainly wild plants and usually growing on metal-rich soils, have been investigated so far (e.g. *Thlaspi caerulescens* - Cd, *Thlaspi rotundifolium* subs – Pb, *Alyssum bertolonii* and *Berkheya coddii* – Ni, *Atriplex confertifolia* – U, *Thlaspi calaminare* – Zn, etc.). In some experiments cultivars have been used for the same purpose (maize, sunflower - U; soybean, etc.).

EXPERIMENTS WITH URANIUM

Uranium in phosphorous fertilizers. Uranium as an alpha and gamma emitting radionuclide, as well as a toxic metal, poses a hazard to humans and the environment. Our investigation was inspired by the interesting question of how much uranium from phosphorous fertilizers can reach plants and their products, and how dangerous it is for humans and the environment. Agricultural production in this country had started to increase rapidly in mid-1960s as a result of the use of mineral fertilizers, including phosphorous fertilizers. The raw material for phosphorous fertilizers production contains a certain amount of uranium (30-300 mg/kg), which can accumulate in upper soil layers and leach into deeper ones, or be uptaken by plants. Its amount therefore depends on the physico-chemical properties of soil, uranium content in the mineral fertilizer and biological properties of a given plant species.

Stationary experiments were set up back in 1964 to investigated 20 combinations of mineral fertilizers. The findings of 1989, 1990 and 1991 showed that uranium content in soils treated with phosphorous fertilizers (compared with untreated plots, i.e. control) increased over the previous 25-year period in all cases. Those differences were found to be significant and highly significant. For example, by annually applying 100kg P_2O_5 per hectare, and knowing that one kilogram of P_2O_5 contains 100 milligrams of uranium, we leave 10 g of uranium in soil each year. If all the uranium were accumulated in the upper 20 cm layer of soil, it would cause an annual uranium content increase of 3 micrograms per 1kg of soil. Despite the fact that natural uranium content in soil is several milligrams per kilogram, and that the increased amount of uranium is still low after the application of phosphorous fertilizers, our results clearly indicate that long-term application of phosphorous fertilizers increases the amount of uranium in soil.

EXPERIMENTS AT KALNA URANIUM MINE

Based on previous experiments, the Serbian Academy of Sciences and Arts initiated in 1990 a research project, titled "Uranium in soil and plants", in an effort to investigate how different crops and some wild plants respond to the growing conditions existing in barren soils of the former uranium mine Kalna, Serbia.

Crop plants. Different cultivars of maize, soybean and sunflower, and some vegetable cultivars were studied. The experiments performed at the location of Kalna showed that some common vegetable plants (e.g. lettuce) absorbed more uranium than sunflower, 1.12 vs. 0.14 mg/kg, and mature plants had higher uranium concentration than young plants (Saric *et al*, 1995). Further experiments with 4 different cultivars of soybean and sunflower and 4 maize inbred lines showed that uranium concentration in aboveground and root parts of plants depended on its content in the environment. The experiments also showed a significant differences among soybean and sunflower cultivars as well as among maize inbred lines (Saric *et al.*, 1999).

Wild plants. Plants were collected near the Kalna mine (Jovanovic et al., 2001) and total contents of uranium, ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K were determined using low-level gamma-spectroscopy. The highest amount of total uranium was found in creeping buttercup (*Ranunculus acer*), while another 11 species (English daisy, yellow rattle, goose grass, wild pansy, sweet woodruff and white clover being a relatively homogeneous group) absorbed considerably lower amounts. Wild pansy (*Viola arvensis*) and creeping buttercup absorbed significantly higher amounts of ^{238}U than any of the other 10 species. The highest absorption of ^{226}Ra was found for wild pansy, while creeping buttercup absorbed half as much but still significantly more than the heterogeneous group of the remaining 10 species. Creeping buttercup absorbed the most of ^{232}Th, compared with the other 11 species. The highest amounts of ^{40}K were absorbed by wild pansy, goose grass and yellow rattle.

Experiments in controlled conditions. Based on previous results concerning barren mine soil and water, we performed experiments with plants growing in nutrient solution (Read-York) under controlled conditions. Maize, sunflower and soybean plants were used. When plants were 2 weeks old, uranyl nitrate solution was added and time-depending uranium concentration was measured in different plant parts using x fluorescence spectroscopic method. Uranium uptake was monitored in whole plants at time intervals up to 100 hours. In these experiments pH value of the nutrient solution was 5.5, while the concentration of added uranium was 70 mg/kg. Uranium absorption rate was found to be the highest in the sunflower root (31580 mg/kg after 100 hours). However, uranium concentration in sunflower leaves was negligible, while in soybean leaves it was 74 mg/kg after 100 hours.

Uptake experiments. Another type of controlled-environment studies included typical uptake experiments. About 2 cm long and 4 days old root segments of sunflower, maize and soybean were incubated in a medium suplemented with different uranium concentrations

(150, 250, 450 and 600 mg/kg; pH = 6.0) and several root segments were then taken out at 5 minute intervals until 1 hour (Fig 1.). Sunflower root segments were found to have evidently the highest uptake rate and the highest uranium content during the given time interval. The diagram clearly indicates that uranium uptake by the root segments of all investigated plants occured by diffusion.

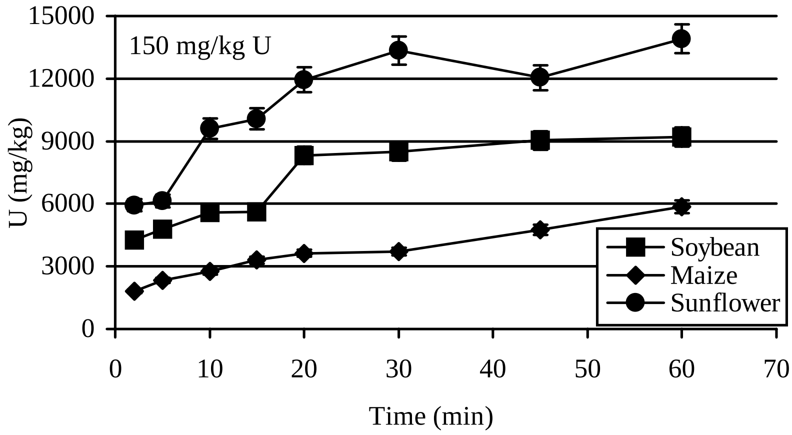

Fig. 1. Uranium uptake rates by root segments

At present, our research is focused on the investigation of different uptake mechanisms of these species. Considering plants as possible uranium phytoremediators and a relatively economical solution, we plan to test different crop cultivars and genotypes both under controlled and field conditions in order to single out the best phytoremediators for future commercial use.

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